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MODIFICATION OF INTERNAL DISCRIMINATIVE STIMULUS CONTROL OF BEH--ETC(U)
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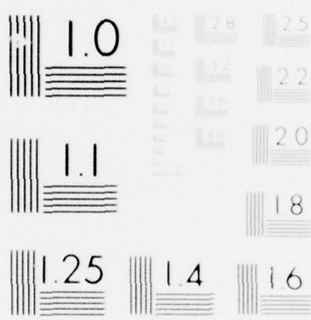

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The behavioral effects of pulsed microwave radiation were determined on rats performing on a reinforcement schedule regulated by internal stimulus control. The reinforcement schedule required that at least eight consecutive responses be made on one response lever before a response on a second lever would be reinforced with food. If the animal switched to the second lever before the count of eight, the sequence of eight responses had to be restarted. Baseline performances over a 6-month period indicated the existence of a discrimination

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MODIFICATION OF INTERNAL DISCRIMINATIVE STIMULUS CONTROL OF BEHAVIOR BY LOW LEVELS OF PULSED MICROWAVE RADIATION

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ABSTRACT

The behavioral effects of pulsed microwave radiation were determined on rats performing on a reinforcement schedule regulated by internal stimulus control. The reinforcement schedule required that at least eight consecutive responses be made on one response lever before a response on a second lever would be reinforced with food. If the animal switched to the second lever before the count of eight, the sequence of eight responses had to be restarted. Baseline performances over a 6-month period indicated the existence of a discrimination of the number of responses counted on the first lever, as switching responses occurred with the largest frequency following eight or more responses. Exposure to a pulsed 2.45 GHz radiation source for 30 minutes with power densities of 5, 10, or 15 mW/cm^2 produced changes in the performance on the fixed consecutive-number schedule. All power densities led to increased frequency of premature switching, with the highest power producing the most disruption of the counting discrimination. Premature switching responses due to radiation exposures were associated with pronounced reductions in the percentage of correctly performed response runs that produced reinforcements. Microwave radiation had no effects on overall or running response rates or on response variability.

INTRODUCTION

There has been a growing interest in the reported effects of exposure to microwave radiation on the nervous system and behavior. Particularly of interest are the biological effects of very low levels of microwave radiation. A wide range of disciplines have begun to investigate the biological effects of low-level nonionizing radiation on the nervous system; these disciplines include electrophysiology, pathology, biochemistry, and behavior analysis [1, 2]. The present study is part of a program concerned with the effects of low-level microwave radiation on the nervous system assessed by changes in ongoing complex behavior in organisms following exposures to microwave radiation. The behavioral baseline used in the present study involved a counting procedure in which a minimum number of consecutive responses on one manipulandum was required before a response on a second manipulandum would be reinforced [3, 4]; the baseline is presumably concerned with an organism's discrimination of its own behavior or the regulation of behavior by subtle internal stimulus control. The behavioral effects of a range of field strengths of pulsed microwave radiation on performance on this baseline were determined.

MATERIAL AND METHODS

The subjects were four male albino rats (NMRI:O[SD]CV, Sprague-Dawley derived) weighing from 250 to 300 g and maintained at approximately 80% of their free-feeding weights by food presented during sessions and by postsession supplemental feeding. They were housed in individual home cages with continuous access to water.

The subjects performed in a rodent cage (21.6 X 24.1 X 20.3 cm) that contained two response levers and a food tray mounted on the front wall. The response levers required a minimum force of approximately 10 g to make an electrical switch closure that was recorded as a response. A pellet feeder located behind the front wall dispensed 45 mg food pellets into the food tray located between the two response levers as the reinforcer. A houselight was mounted on the top of the front wall. The rodent cage was mounted inside a sound-reducing enclosure with a filtered ventilation system. Scheduling and recording of experimental sessions, as well as data analysis, were accomplished by a general-purpose digital computer connected to the rodent cage by appropriate interfacing.

The subjects were trained by the method of successive approximation to produce a food reinforcement by pressing the right response lever once followed by a single response on the left lever. Over a number of sessions the requirement on the right lever was increased to eight responses. The final schedule required that at least eight consecutive responses be made on the right lever before a response on the left lever would produce a food reinforcement. If a subject switched to the left lever before the count of eight was completed, no consequence occurred except that the sequence of eight responses was reinstated. The subjects performed on the schedule for five sessions per week. Each daily experimental session lasted until 60 food reinforcements had been obtained, at which point the houselight was cut off, the response levers were electronically disconnected, and the session was terminated. Subjects were exposed to the schedule for 6 months to ensure stability in baseline responding before exposure to microwave radiation.

The subjects were exposed to microwave radiation immediately before experimental sessions on one day during a week. Usually two subjects were irradiated on the same day. They were exposed to radiation for 30-minute durations; the experimental sessions began 5 to 10 minutes after the end of a microwave exposure. The microwave generator (Applied Microwave Laboratory, Model PH40K) produced a pulsed radiation source that operated at 2.450 GHz, with the pulse width set at 1 µsec and the pulse-repetition frequency set at 500 Hz. The energy source was coupled through wave-guide transmission lines to a 24.1 X 17.8 cm rectangular horn (Waveline). The horn was oriented to give a vertically polarized electric field. Power to the horn was measured by a power meter (Hewlett-Packard, Model 432A) inserted with a directional coupler into the wave-guide lines connecting the generator to the horn.

All irradiations were conducted in a chamber lined with microwave-absorbing material (Echosorb FR340). The subjects were placed in a sleeve holder constructed of fine plastic mesh, which produced negligible perturbation of the field. Figure 1 illustrates the radiation chamber and apparatus arrangement. The subjects were exposed to a number of sham irradiation exposures during which they were placed in the sleeve holder for a duration of 30 minutes with all equipment on, but no forward power. All four subjects were exposed to three different power densities (5, 10, and 15 mW/cm^2) two or three times each in a semirandom sequence. The subjects performed on the baseline schedule every day between the microwave exposures in order to observe behavioral recovery from microwave exposures and to provide a continuous baseline to which exposure sessions could be compared. All of the data

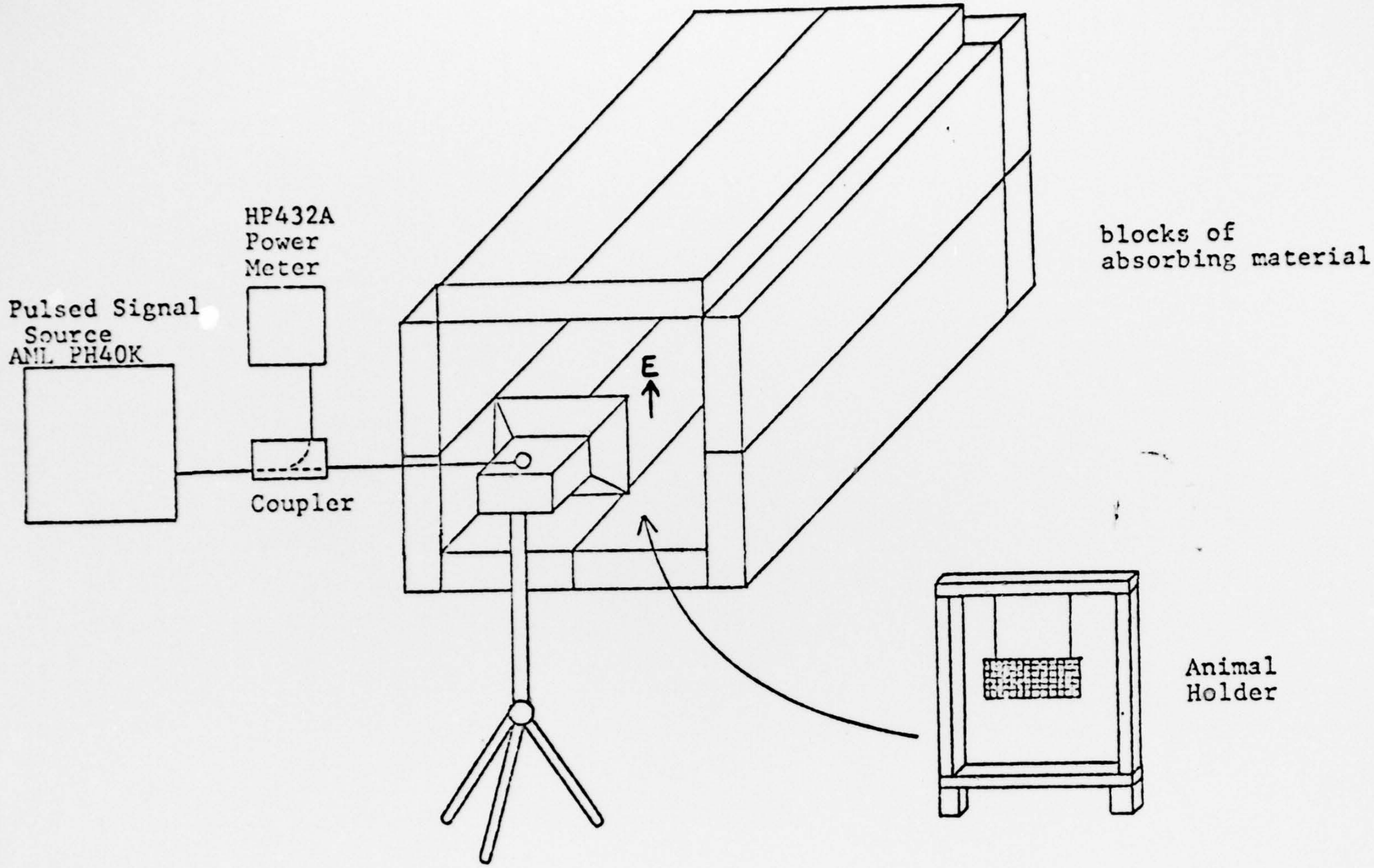

Figure 1. Schematic of radiation chamber, apparatus, and animal holder.

and measurements presented in the study are based on the last two exposures at each power density investigated and the last two sham exposures for each subject. All exposures were conducted under near-field conditions with the subjects separated from the antenna by either 2.5 or 3.75 wavelengths and oriented perpendicularly to both the direction of propagation and the electric field vector of the microwaves. The heads of the subjects, placed along the boresight of the antenna, were exposed to three different field intensities. The intensity of the microwave field, used for an exposure, was determined by placing a Narda Microline probe (Model 8323) at the position of the subject's head in the absence of the subject. The three intensities, measured in this fashion, were approximately 5, 10, and 15 mW/cm^2.

The Narda probe, because of its large size, could not provide the spatial resolution and maneuverability required for the accurate mapping of the near fields utilized for the animal exposures. A miniature probe, developed by the Bureau of Radiological Health [5], was used to map spatial variations and standing waves as well as to quantify the relative magnitudes of the three components of the electric field, both with and without the animal present in the chamber. As the miniature probe was designed for use in C.W. fields, a 2.450 GHz C.W. generator was coupled to the antenna for these measurements.

The core temperatures of the rats were measured before and after a number of radiation exposures with a standard rectal probe. In addition, the core temperature was measured in the field during a series of microwave exposures using a small probe designed for use in microwave environments [6].

DATA ANALYSIS

Following each daily experimental session, five behavior measures were calculated:

(1) Overall response rate: the rate of responding (responses per second) during an entire session.

(2) Running rate: the rate (responses per second) at which a subject responded on the right lever between a prior response on the left lever and a response on the left lever that ended the run. Both the mean rate at which runs were emitted and the standard deviation were calculated for a session.

(3) Run length: the mean number of responses emitted on the right lever between responses on the left lever. The standard deviations for the runs were also calculated.

(4) Reinforced runs: the percentage of runs in each session that were long enough to produce reinforcement.

(5) Relative frequency: the frequency distribution of all run lengths that occurred during an experimental session.

RESULTS AND DISCUSSION

The subjects exhibited a discrimination of the number of responses required on the right response lever, as the largest proportion of left-lever responses occurred following the requirement of eight or more responses on the right lever. The main finding of the present study is that all three of the power densities explored led to changes in performance on the behavior baseline. Performance always recovered to within baseline values by the session immediately following microwave exposure.

Figure 2 shows changes in the percentage of runs that were long enough to produce reinforcement as a function of increasing power density. The percentage of correct runs declined as a result of exposure in increasing power densities [$F(3, 9) = 20.3$, $p<.001$]. The percentage of correct runs dropped from close to 80% for baseline to below 50% at 15 mW/cm^2. Associated with the decline in the percentage of correct runs was a decrease in the mean

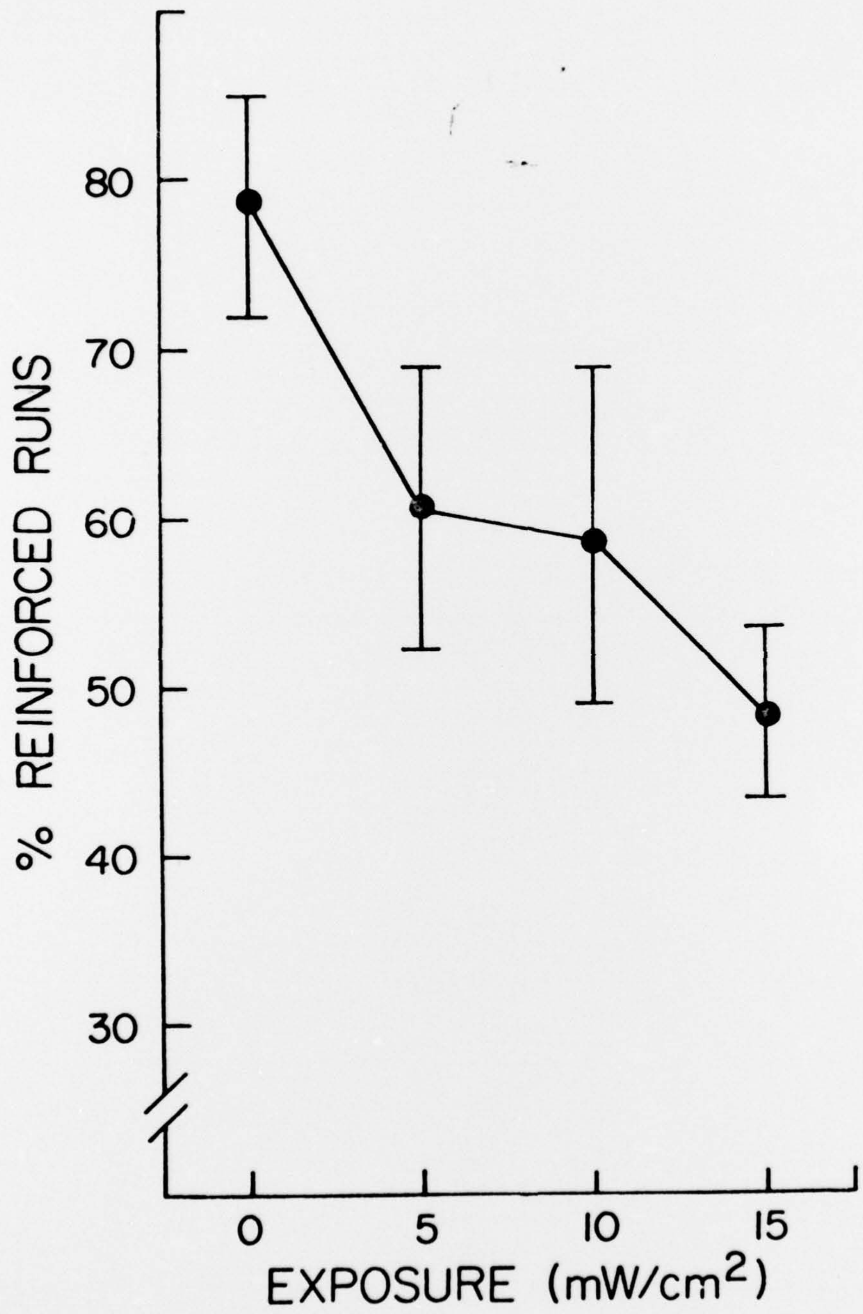

Figure 2. Changes in the percentage of reinforced runs as a function of microwave-radiation intensity. Zero exposure indicates baseline performance following sham irradiations. Each data point is the mean of four subjects and brackets show standard errors.

number of responses emitted on the right lever between responses on the left lever (run length). As shown in the top of Fig. 3, the mean run length decreased from baseline to the highest power density [$F(3, 9) = 18.2$, $p < .01$]. The variability of run lengths as reflected by the standard deviation of each dose showed no systematic trends (lower half of Fig. 3).

The decline in percentage of correct runs as a result of exposure to microwave radiation is a direct result of an increasing number of run lengths that were less than the required eight responses. Figure 4 shows the relative distribution of various run lengths for baseline sessions. The relative frequency distribution indicates that the highest frequency occurred at a run length of eight, with the largest proportion of runs indicating lengths of eight or longer. The increase in run lengths that were shorter than the required run length as a result of radiation exposure can be seen in Fig. 5, which shows the relative increase in the proportion of shorter runs as a function of power density. The run-length distribution is shifted toward shorter run lengths after microwave-radiation exposure.

Examples of performance on baseline sessions and following exposure to the three power densities may be seen for two of the subjects in Figs. 6 and 7. The records indicate recorded responses on the right lever. If the run was eight responses in length or greater following a run of responses on the right lever, a response on the left lever produced a food reinforcement as indicated by a pip on the record. The baseline records indicate that the schedule produces a high rate of responding preceded by a pause after reinforcement. Such a biphasic pattern is quite typical of performance on a fixed-ratio schedule of reinforcement. Since all sessions were terminated when 60 reinforcements had been obtained, the increase in the number of short, incorrect response runs during microwave sessions can be assessed by the increased number of responses in a record. Generally, the cumulative response records show that the number of right-lever responses (those too short to produce reinforcement) increased with increasing power densities. Particularly in the records for the 10 and 15 mW/cm^2 sessions, long runs of responses can be seen with few reinforcements obtained. In addition to the increase in incorrect-length response runs, the cumulative records for the higher doses show that the response patterns became disrupted.

Even though there were definite changes in the proportion of correct runs and in the response patterns as a function of microwave exposure, mean running rate showed no systematic changes (Fig. 8). Neither the mean running rates nor the variability of rates showed any clear changes as a result of increases in power density. Overall response rates, as shown in Fig. 9, showed only a slight trend toward declining with increasing dose of exposure.

Another important characteristic of the behavioral baseline generated by the experimental procedure is that the lengths of consecutive response runs develop sequential dependencies. That is, the length of a particular response run depends upon the length of the preceding run [4]. The dependency of run length on preceding runs can be seen for baseline sessions in the relation presented in Fig. 10. The baseline data points, particularly for the middle-run-length values, indicate that following runs tend to be slightly longer than preceding runs. The regression line fitted to these data points shows this subtle relationship. As can be seen by the unfilled data points in Fig. 10, the sequential dependency is disrupted and the degree of relationship is less after microwave exposure. Regression lines fitted to the data for all power densities are shown in Fig. 11. Although there is no clear differentiation among the slopes for the three microwave intensities, they all are clearly different from the baseline relationship. Aside from the effects of microwave radiation in producing increases in response runs that are too short to obtain reinforcement and the associated response-pattern changes,

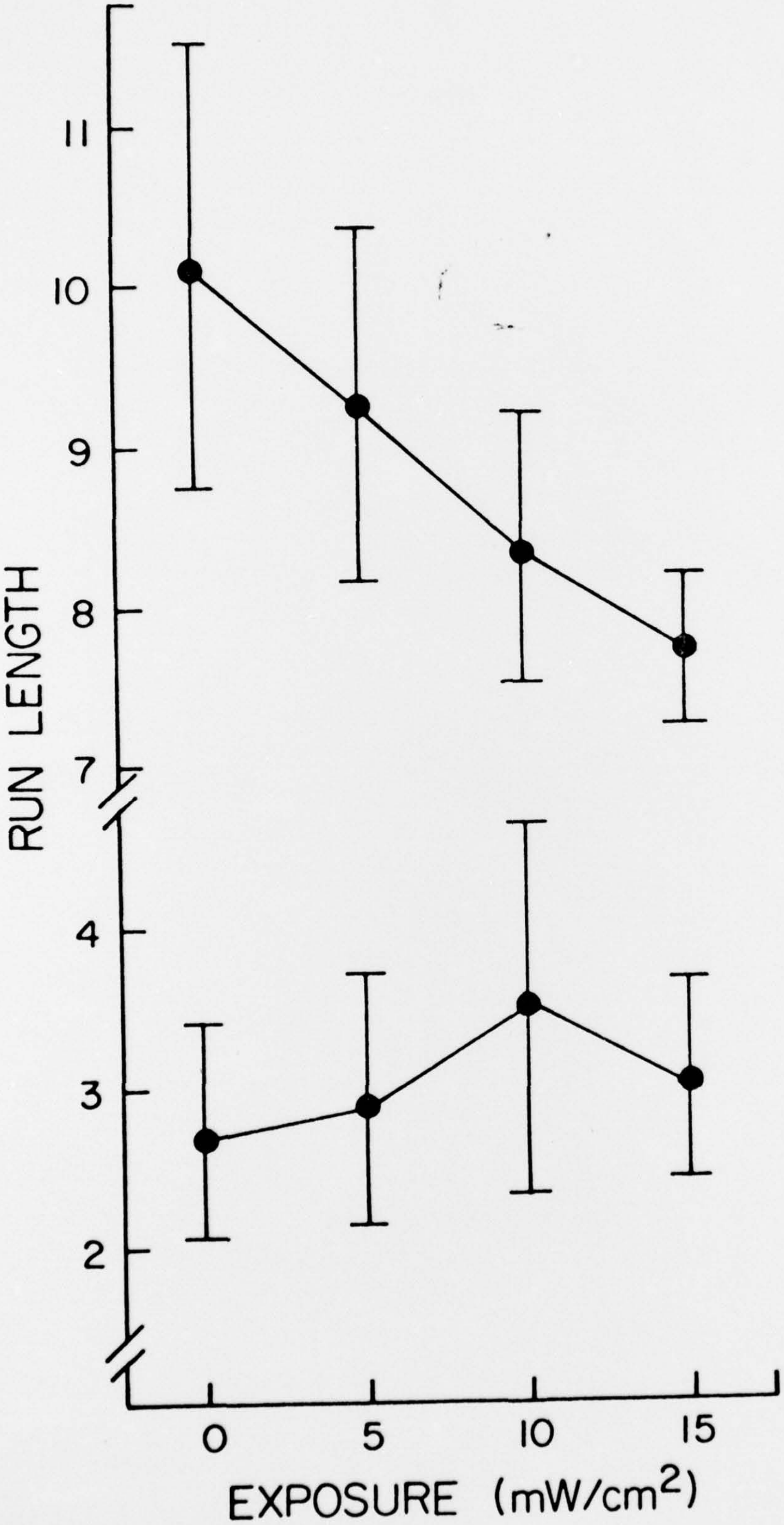

Figure 3. Changes in run length as a function of microwave-radiation. Zero exposure indicates performance during sham irradiation. The upper function shows run length and the bottom function shows the standard deviation of a session. Each point is the mean of the four subjects and brackets indicate standard errors.

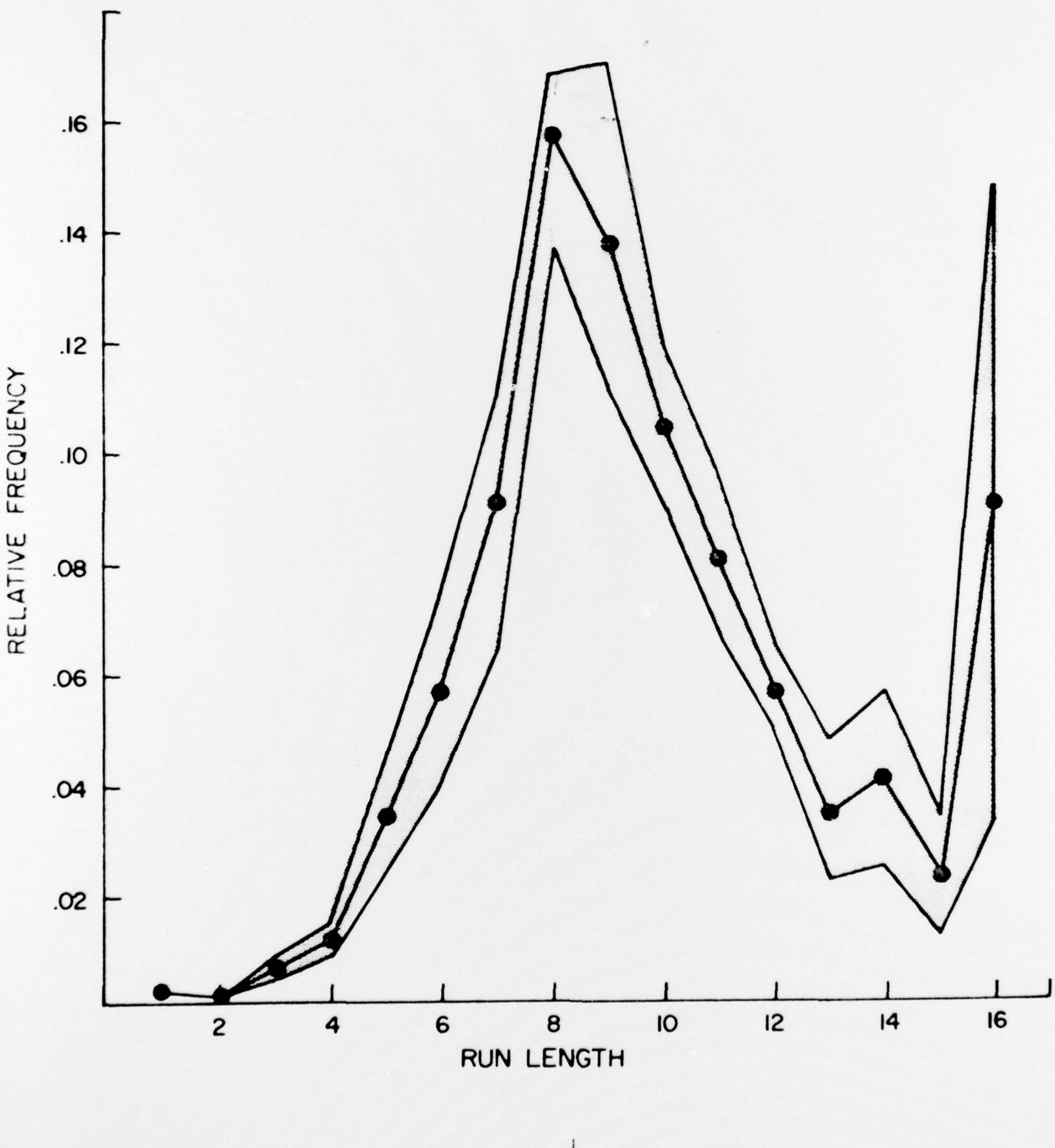

Figure 4. Relative frequency distribution of run lengths. Data points are the mean of four subjects and the shaded area indicates standard errors. The last data point shows all runs that were 16 responses or more in length.

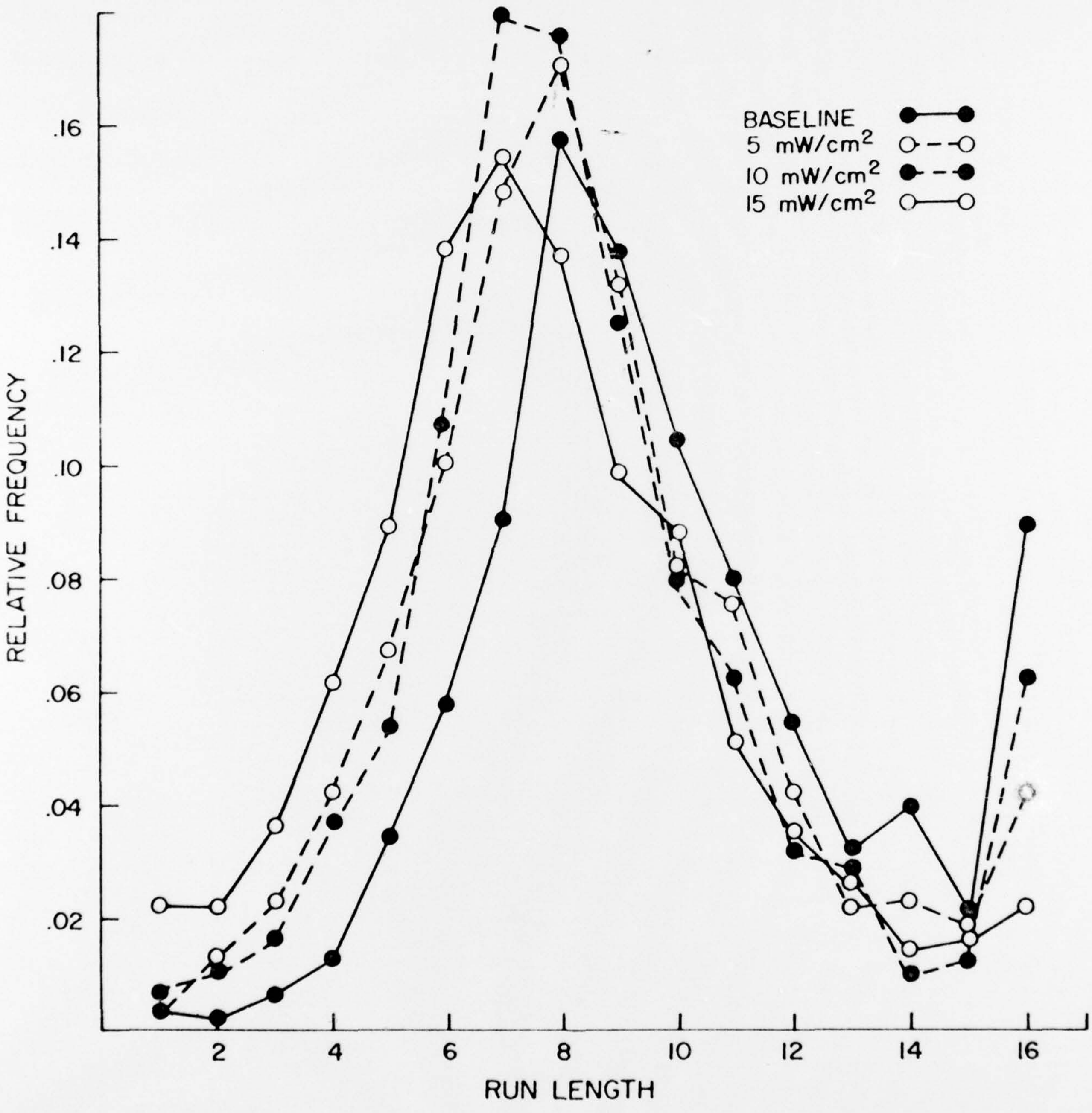

Figure 5. Relative frequency distribution of run lengths for baseline and three microwave-radiation intensities. The data points plotted at a run length of 16 represent runs of that length or greater.

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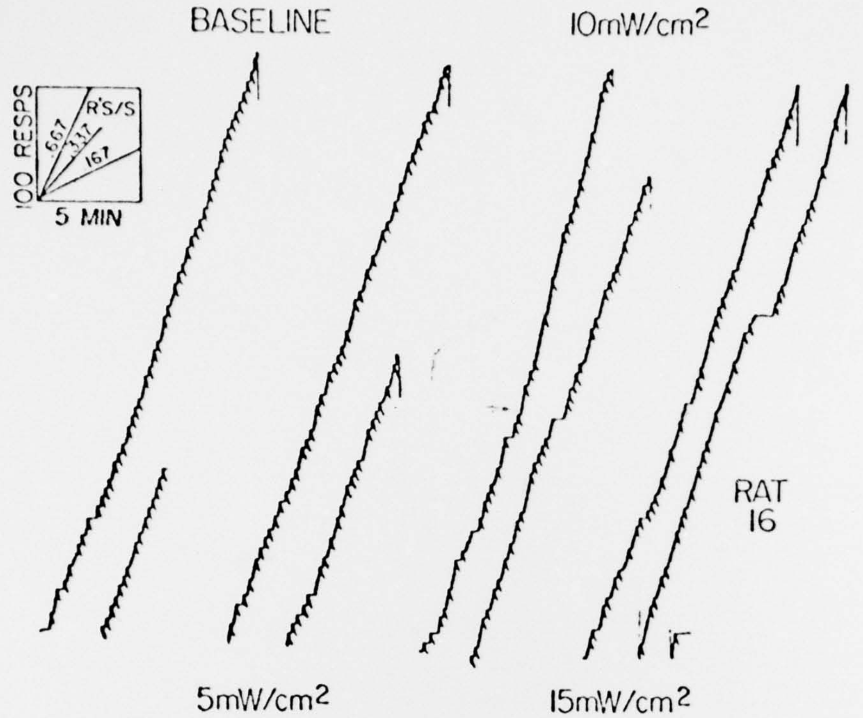

Figure 6. Cumulative response records of Subject 16 from baseline session and three microwave-radiation intensities. Recorded right-lever responses stepped the recording pen upwards. Pips indicate a left-lever response that followed a correct-length response run and produced a food reinforcement. The records have been cut and "telescoped" to conserve space.

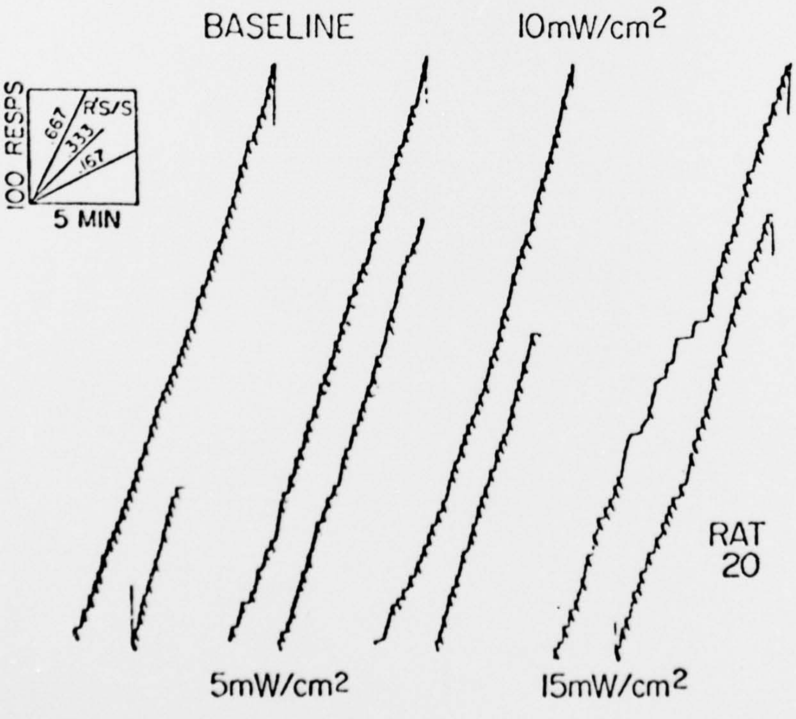

Figure 7. Cumulative response records of Subject 20. Aspects of the records are the same as in Fig. 5.

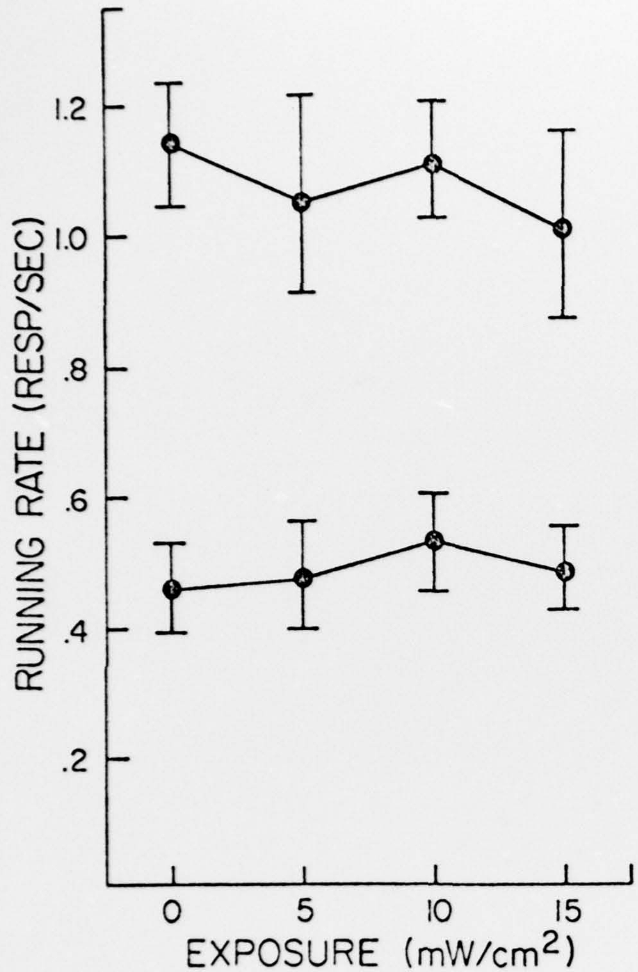

Figure 8. Running rates as a function of microwave radiation. Each data point is based upon the mean of four subjects and brackets indicate standard deviation. Zero exposure is for sham irradiation. The upper function shows running rate and the bottom function shows the standard deviation.

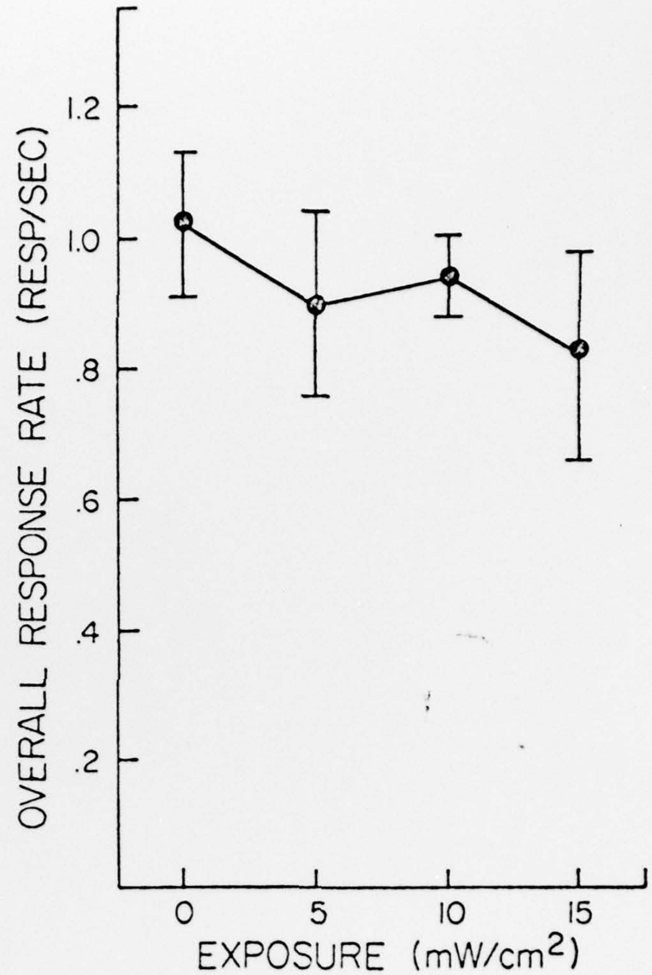

Figure 9. Overall response rate as a function of microwave radiation. Zero exposure indicates performance following sham exposures. Each point is the mean of four subjects and brackets show standard errors.

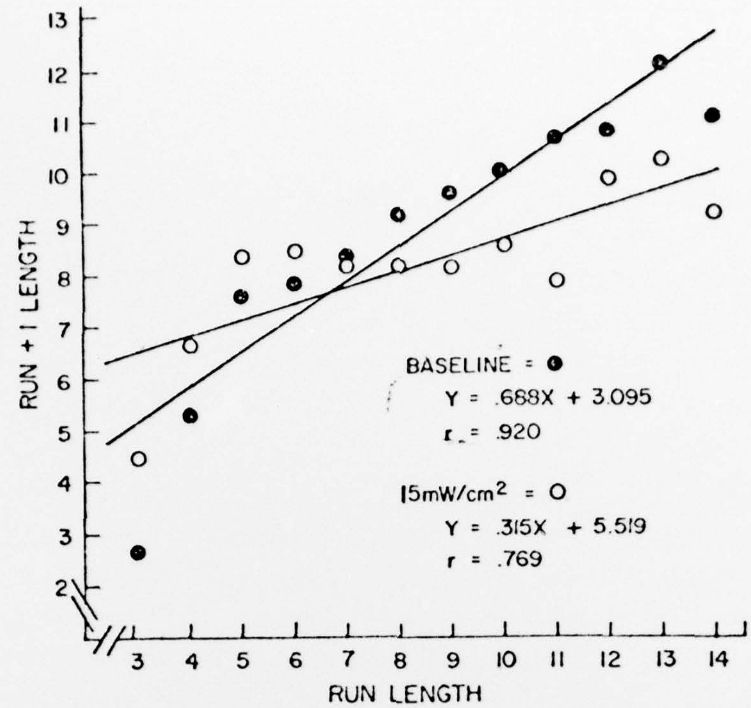

Figure 10. Relation of run length (Run plus 1) to preceding run length. Filled points indicate baseline and unfilled points performance following microwave intensity of 15 mW/cm^2. The regression lines were fit to the data by the method of least squares.

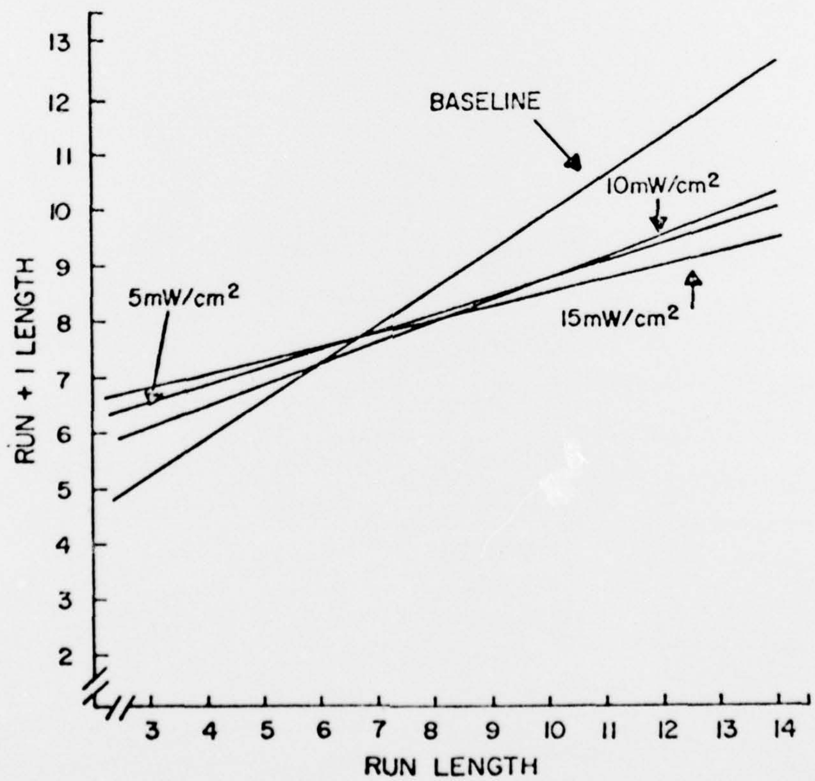

Figure 11. Relationship between run length (Run plus 1) to preceding run length for baseline and three microwave-radiation values. For clarity, only regression lines are shown, which were fit to data by least squares method.

microwave radiation appears to produce second-order changes in the more subtle dependency aspects of the behavior controlled by the reinforcement schedule.

An examination of the spatial variation of $|E|^2$ with the Bureau of Radiological Health probe, (where $|E|^2$ is the magnitude squared of the electric field vector), provided information about the magnitude of the reflections caused by the subject. Without the subject in the radiation chamber, standing waves created by reflections from the chamber walls caused the amplitude of the sinusoidal spatial variations of $|E|^2$ in the neighborhood of the position of the subject's head during exposure to be no more than 10% of $|E|^2$ at this position. With the subject in the chamber, reflections from the subject increased the amplitude of such sinusoidal variations between the antenna and the subject's head to be about 50% of the value of $|E|^2$ at the subject's head. Contributions of components of the electric field vector other than the vertical at the subject were shown to be negligible.

The behavioral changes observed in the present study as a result of low-level microwave exposure show a monotonic relationship with increased power density, which indicates that the behavioral modifications produced by the microwave exposures are related to field strength.

None of the temperature measurements, taken immediately after or during microwave exposure, indicated any temperature changes of the body that were outside of normal variations. No correlation was observed between any temperature fluctuation and the presence or absence of microwaves.

ACKNOWLEDGMENTS

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